



Propulsion

Mike Osborn

NRL

202-767-9168

mosborn@space.nrl.navy.mil



Top Level Functional Requirements



- **Provide Thrust for Spacecraft Orbit Raising, Attitude Control, and Stationkeeping**
- **Provide Single Fault Tolerant Design**
 - Thruster Failure
 - Valve Leakage
- **5 Year Mission Life**
 - Design For Delivery by January 2002
 - Derived From Integrated Master Schedule
 - Design and Qualify for Worst Case Mission and Launch Environments With Margin
 - New or Re-Designed Systems Will Have Protoflight Testing
- **Meet Launch Base Safety Requirements and Verification Process**
 - EWR-127-1
- **Support Science Mission Requirements**
 - Minimize CG Migration
 - Plume Contamination
- **Minimize Cost and Schedule Risk**
 - Provide Most Flexible Design With Given Schedule and Budget



Propulsion Derived Requirements (1 of 3)



- **Provide Delta V Thrust Through + Z Axis (Velocity Vector) for Orbital Maneuvers**
 - **Correct Delta 7425 Launch Vehicle Insertion Error**
 - 1st/2nd Stage Pointing Error
 - 3rd Stage (STAR 48) Pointing and Impulse Errors
 - **Correct Transfer Stage (STAR 30BP) Pointing and Impulse Errors**
 - **Total Impulse Error Requires Additional Impulse Capability**
 - **Pointing Error Produce Inclination Changes**
 - Acceptability Above 28° Must Be Evaluated for No Correction
 - **De-Orbit Transfer Stage Before Science Mission**
 - **De-Orbit From GEO Position for Orbital Debris Mitigation**
- **Provide Vehicle 3 Axis Attitude Control**
 - **Correct for Delta V Thrust Misalignment With CG**
 - **Nutation Control**
 - Solid Rocket Motor Firing
 - Science Collection



Propulsion Derived Requirements (2 of 3)



- **Provide Vehicle 3 Axis Attitude Control (Continued)**
 - **Precession Control (Backup for Solar Precession)**
 - Solid Rocket Motor Firing
 - Science Collection
 - **Spin Control (About Vehicle Z Axis-Roll)**
 - Requires Pure Torque Couples
 - Spin Stabilize for Solid AKM Firing 40-100 RPM
 - Rotation Control for Science Mission
 - 1 Revolution Per 40 Minutes
- **Provide Stationkeeping (Drag Make Up) Delta Velocity**
 - **No North-South Stationkeeping Requirement**
 - Allows Inclination Drift
 - **East-West Stationkeeping**
 - 1 Degree Tolerance for GEO Orbital Position Allocation
 - Requirement May Be Removed via Orbit Optimization



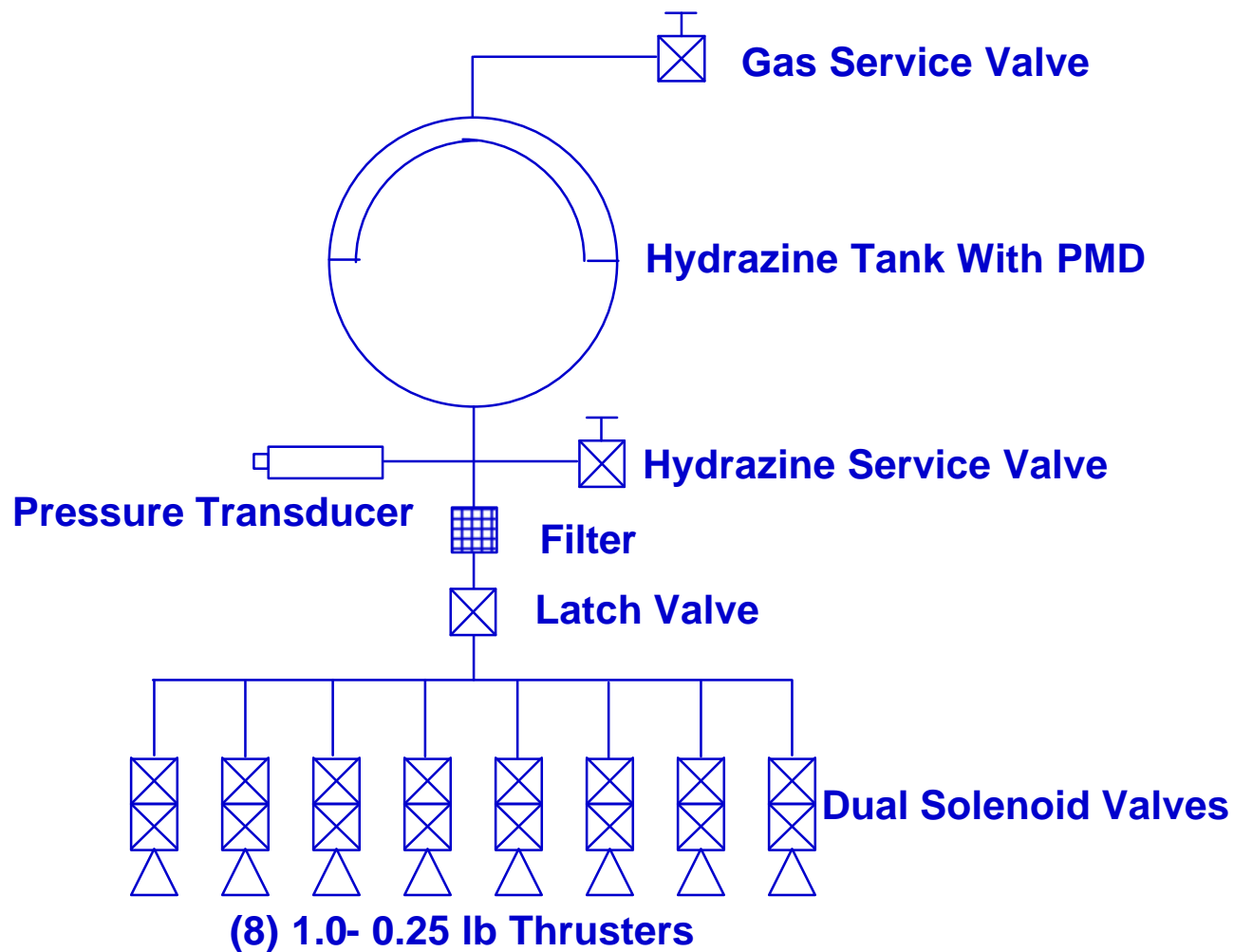
Propulsion Derived Requirements (3 of 3)



- **Mono-Propellant Hydrazine Propellant System**
 - Moderate Mission Total Impulse Requirements
 - Blowdown Pressurization
- **Positive Expulsion Tank Required for Precision CG Alignment During Expulsion**
 - Science Mission Requirement
 - Eliminates Passive PMD Designs (i.e., Vanes, Sumps)
- **Drop Off AKM Stage Due to Uncertainty in Post Burn Mass Properties**
 - Science Mission Requirements for CG Knowledge & Alignment
- **De-Orbit in Accordance With NASA Policy Directive (NPD) 8710.XX**
 - GEO Is an Active Orbit Requiring Removal of Orbital Debris
 - 300 Km Above GEO Disposal Orbit
 - Applies to Solid Apogee Transfer Stage
 - Final Disposal of FAME Vehicle



FAME Propulsion Schematic





Current Baseline/Approach



- **One Centrally Located Pressurized Monopropellant Hydrazine Tank**
 - Contains a Propellant Management Device (PMD)
 - Blowdown Pressurization Ratio Dependent on Tank Selection and Propellant Load (Nominal 4:1)
- **Eight 1.0 lb to 0.25 lb Thrusters (Beginning-of-Life vs. End-of-Life)**
 - 4 +Z Thruster for Delta V
 - 4 \pm Y Thrusters for Spin Control and Attitude Control
 - Series Thruster Valves (Leakage Protection)
 - Each Thruster Has a Catalyst Bed Heater
- **Latch Valve Provides Leakage Tolerance and Personnel Protection**
- **One Pressure Transducer Provides Telemetry Data**
 - Determines Propellant Usage
 - Helps Predict Thruster Performance
- **Two Fill Valves for Propellant Loading and System Check-Out**



Propulsion Trade Studies (1 of 2)



- **Monopropellant Hydrazine System Selected for FAME**
- **Other Propellant Systems Considered Include:**
 - **Cold and Warm Gas Systems**
 - Volumetrically Large and Massive for FAME Total Impulse
 - **Bi-Propellant System**
 - Higher Specific Impulse
 - Less Propellant Weight Than Hydrazine
 - High System Complexity
 - Two Propellant Feed Systems
 - Costly Components
 - Higher Force and Impulse Bit Thrusters Not Suitable for Precise Attitude Control
 - **Electric Propulsion**
 - Low Thrust Good for Precision Impulse Bit
 - High System Complexity
 - Separate Propellant Feed System
 - Separate Power System
 - Low Total Impulse Required Does Not Justify High Dry Mass



Propulsion Trade Studies (2 of 2)



- **Thruster Selection**
 - Multiple Vendors and Designs
 - Dedicated Spin Axis Precession (SAP) Thrusters vs. Dual Spin/ SAP
- **Tank Selection**
 - Multiple Vendors and Designs
 - Single Tank vs. Pressurization Tank
 - Tank Geometry
 - Oblate Spheroid Desired but Has Limited Availability
 - Mounting Options
 - Elastomeric Tank Bladder vs. Metal Diaphragm
 - New Tank Design and Qualification Requires 18 Months ARO
- **Buy vs. Lease SRM Support Hardware**
 - Shipping Container
 - Turn-Over Stand
 - Proof and Leak Test Fixtures



Propulsion Analysis From CSR



- **Launch Vehicle**
 - To Determine Throw Margin
 - Evaluate FAME Injection Orbit
 - Preliminary Analysis Based on Initial Proposal Masses
 - Evaluate Injection Errors
- **STAR 30BP AKM**
 - Determine Margins and Offload Requirements
 - Evaluate Total Impulse and Pointing Errors
- **On-Board Hydrazine System**
 - Propellant Selection and System Sizing
 - Propellant Analysis
 - Margins Analysis



Apogee Kick Motor (AKM) for GEO Injection



- **Thiokol STAR 30 BP Solid Rocket Motor**
 - Hughes HS-376 AKM
 - > 60 STAR 30 Series Flights
 - TI 6AL-4V Case
 - Carbon-Carbon Throat With Carbon-Phenolic Nozzle
- **Performance**
 - Total Impulse 328,200 lb-sec
 - Average Thrust 6070 lb
 - Burn Time 55 sec
 - Effective Specific Impulse 292 sec
 - Spin Capability 40 to 100 rpm
 - Capable of 20% Propellant Offload
- **Weights**
 - Total Loaded 1196.7 lb
 - Propellant 113.6 lb
 - Empty Weight 72 lb
- **Current Mass Estimates Indicate 10% Propellant Offload**



Propellant Budget



Manuever	Prop Used (kg)
Initial Acquisition & Pointing	0.9
Spin-up FAME with SRM	5.1
Active Nutation Control	2.0
Despin FAME with SRM	5.1
AKM Total Impulse Error (0.5%)	3.4
Jetison SRM and Adaptor	0.1
1° AKM Pointing (i=.63°) Error Correction	0.0
Decrease Perigee by 300 km to Final GEO Orbit	1.3
Decrease Apogee by 300 km to Final GEO Orbit	1.3
N-S Station keeping (1 °/ Year)	0.0
E-W Station keeping (for ± 1° Longitude)	2.4
Spin-up for Mission	0.2
5 Yr Mission ACS (All Thruster Precession)	7.3
Raise Apogee by 300 km to deorbit	1.3
Raise perigee by 300 km Miles to deorbit	1.3
20 Mission Safe Hold Manuevers	3.4
2% Unusable Residual	2.2
25% Fuel Margin	12.6
Total	49.8



Issues (1 of 2)



- **Tank Selection**
 - **PMD Selection Determines Delivery Schedule**
 - **Oblate Spheroid Shape Is Desirable**
 - **Reduces Spacecraft Overall Height Allowing Preferred Sun Angle Between the Sun Shield and Payload**
 - **Heritage Design Is Desirable**
 - **New Design and Qualification Are Possible but Time Consuming and Costly**
- **Schedule**
 - **Long Lead Time Procurements Are Required**
 - **Tank Delivery Is 18 Months ARO for New Design and Qualification**
 - **Thrusters Delivery Is 14 Months ARO**
 - **Major Procurements Required Before CDR**
 - **Requires Firm and Early Mission Design**
 - **Expedited Procurement Process Is Required**
 - **180 Day Contracting Period Is Unacceptable for Tank and Thruster Procurements**



Issues (2 of 2)



- **Thruster Solar Precession**
 - **Possible Requirement for Solar Pressure Precession Backup**
 - **If Hydrazine Minimum Impulse Is Too High, a Small Impulse Bit Attitude Control System May Be Required**
 - **Cold Gas Is Possible but Must Be Fully Evaluated**
 - **Additional Propellant System Would Augment Hydrazine**
 - **Additional Costs & Effort Above Previously Quoted for CSR**
 - **Requirement Evaluation and Definition by Systems Requirements Review (SRR)**
 - **Long Lead Items Required (12 Months for the Tank)**



Top Level Schedule

